USAARL Report No. 2009-02

Noise and Reverberation Reduction in Post Chapel Activity Room

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Sensory Research Division

November 2008

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*: 18 NOV 2008

2. REPORT TYPE: FINAL

3. DATES COVERED *(From - To)*:

4. TITLE AND SUBTITLE
Noise and Reverberation Reduction in Post Chapel Activity Room

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

6. AUTHOR(S)
Adrianus J.M. Houtsma

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, Alabama 36362-0577

8. PERFORMING ORGANIZATION REPORT NUMBER
USAARL 2009-02

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
In the fall of 2005 the author was contacted by the Fort Rucker Post Chaplain to investigate and offer some suggestions for improving the acoustics in the chapel’s activity room. Visual inspection and Sabine-model calculations led to the recommendation to install additional sound-absorbing surface area. In January 2006, the Fort Rucker Directorate of Public Works presented a contractor’s proposal to add 700 square feet of absorbing baffles suspended from the ceiling. This plan was later changed to include an additional 1000 square feet of absorbing wall panel to the already existing wall-mounted paneling. This report contains results of reverberation time measurements, made before and after installation of the additional paneling. It shows that the renovation was effective, reducing reverberation times at all frequencies by almost a factor of two except at the lowest measured frequency (125 Hz) where reverberation time was unaffected. It is expected that, with a carefully tuned electronic public address system, the space should now be acoustically functional for worship, conferences, theater and music performances, and social functions.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLAS	UNCLAS	UNCLAS	SAR	26	Loraine Parish St. Onge, PhD
					19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

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Acknowledgment

The author wishes to thank Dr. Loraine P. St. Onge for her exceptional efforts in editing this report.

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Introduction

Immediately west of the Fort Rucker Post main chapel is an annex (Building 8939) containing office space and a large "Activity Room." This space has a floor surface of 56 x 43 feet (ft), a high cathedral ceiling, and a volume estimated at 54,000 cubic feet. Walls are made of painted concrete blocks, ceiling material has low acoustic absorption, and the floor is covered with hard, sound-reflecting tile. The lower part (about 10 ft up from the floor) of the rear and side walls are covered with sound absorbing panels. The front wall has a large stage opening which, when closed off by the stage curtain, absorbs additional sound.

The activity room is used for a variety of functions, including religious services, conferences, music and theatre performances, and social gatherings. Many complaints were made about the bad acoustics of the space, specifically the high noise level during social gatherings and the excessive reverberation during presentations, lectures or sermons, making speech nearly incomprehensible. Although the facility included a public address (PA) system, the two loudspeakers mounted high on the front wall were placed in the reverberant field (too far from the audience), thus contributing even more to the reverberation problem.

An inspection and acoustic analysis by the author in the Fall of 2005 led to the suggestions to either cover the tile floor with carpet or install a considerable amount of additional wall-mounted sound-absorbing material. The first option was not implemented because carpet is much more difficult to clean than vinyl tiles. Therefore, a contractor's proposal was received, calling for the installation of 22, 8 × 4 ft ceiling-suspended acoustic baffles, adding 704 square feet (ft^2) of sound-absorbing surface area (Fort Rucker DPW-PE, H.R. Schroeder and G.L. Talbert, January 3, 2006). Before the contractor's plan was executed, a series of acoustical measurements were made to obtain a baseline of reverberation times of the space in its original condition.

The overhead ceiling baffle proposal was never executed but, instead, an additional amount (about 1000 ft^2) of wall-mounted sound-absorbing panel material was added to the rear and side walls above the existing acoustic paneling. Figures 1a- through 1d provide an illustration of the four walls and their acoustical treatment; the dark-blue band represents the newly-installed added acoustic paneling. In June 2007, a second set of reverberation time measurements was made to quantitatively document the subjective acoustic improvement reported by the activity room users. This report details the equipment and methods used, the raw acoustic results, and the mathematics of extracting RT_{60} reverberation times (i.e., the time required for a sound to decay by 60 decibels [db] in a space after the sound source is turned off). The report is also intended to demonstrate a relatively simple method to take such measurements using general-purpose equipment and dedicated signal processing software.

Figure 1a. Chapel Annex, north wall, with stage closed off by curtain.

Figure 1c. West (left side) wall.

Figure 1b. South (rear) wall.

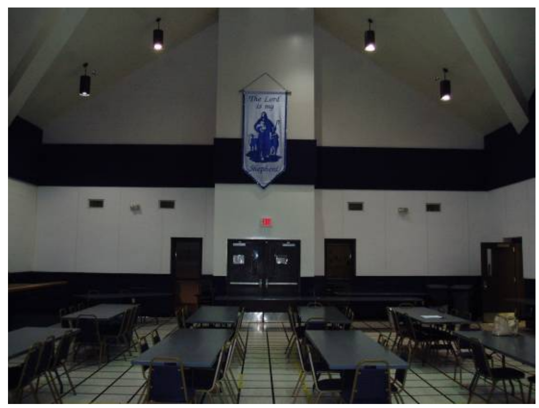


Figure 1d. East (right side) wall.

The lower white-colored wall segments of rear and side walls show the original sound-absorbing paneling. The dark-blue covered wall segments are the newly added sound-absorbing wall panels. The white-colored areas above the blue panels are acoustically untreated brick wall segments.

Equipment and method

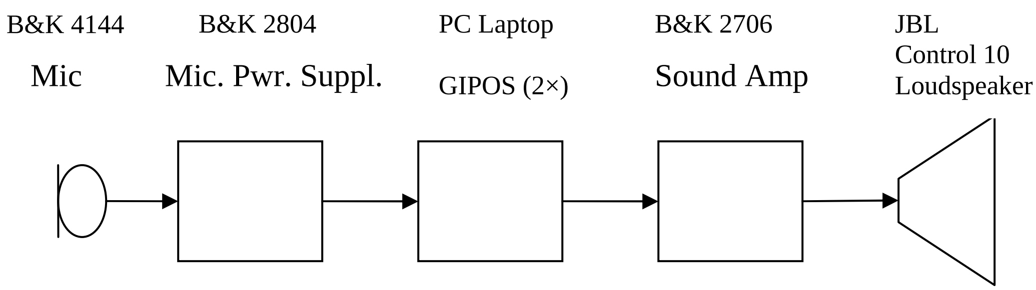


Figure 2. Equipment diagram for reverberation time measurement.

The equipment used for reverberation time measurements is shown in Figure 2. The setup incorporates sound generation and playback, shown on the right-hand side of the diagram, and simultaneously records the space's acoustic response as shown on the left-hand side.

The central element in the setup is a laptop computer with Graphical Interactive Processing of Speech (GIPOS©, Technical University Eindhoven, The Netherlands) software that allows sound digital recording, advanced sound analysis, sound editing, and sound playback. Pink noise generated by a Brüel & Kjær Type 4105 noise generator was digitally recorded in 1-second (s) on and off intervals, and stored on disc as a wave (.wav) file. Pink noise is a broadband random process that has a power spectrum inversely proportional to frequency (1/f). Therefore, the power is constant in successive octave bands, so that an octave-band spectral analysis will show a flat spectrum. This sound file, comprising four, 1-s noise bursts and four, 1-s silent periods, was played through the laptop's headphone output and a Brüel & Kjær Type 2706 audio power amplifier into a JBL Control 10 loudspeaker unit using the GIPOS playback function. The loudspeaker was placed front-center stage facing the activity room.

A second, simultaneously running GIPOS process on the same laptop computer recorded the room's acoustic response. To this end, a Brüel & Kjær Type 4144 1-inch (in) measurement microphone attached to a Brüel & Kjær Type 2619 preamplifier (preamp) was connected to a Brüel & Kjær Type 2804 microphone power supply, and the output was connected to the laptop sound card's microphone input. Since the sound card's playback and recording functions were independent, a source wave could be played and its response recorded simultaneously.
All recordings were made at a sampling frequency of 16 kilohertz (kHz), allowing measurement and analysis up to 8 kHz. Reverberation responses were analyzed broadband (i.e., for all

frequencies together) and in separate octave bands centered at 125, 250, 500, 1000, 2000, and 4000 Hz.

Broadband room responses are shown in Figure 3 below, where the top trace shows the (original) pink-noise pulsed waveform source being played into the room, and the bottom trace shows the room's response as picked up by the microphone. The left-hand picture is from the room before the treatment, and the right-hand picture from the room after additional absorbing panels had been installed. Broadband reverberation time is reflected by the time constant of the exponentially decaying sound images of the responses after the sound source is turned off. Comparing both pictures, it can be readily seen that sound decay time constants have been shortened by the installation of additional sound-absorbing paneling. A further quantification of this result is presented in the next section.

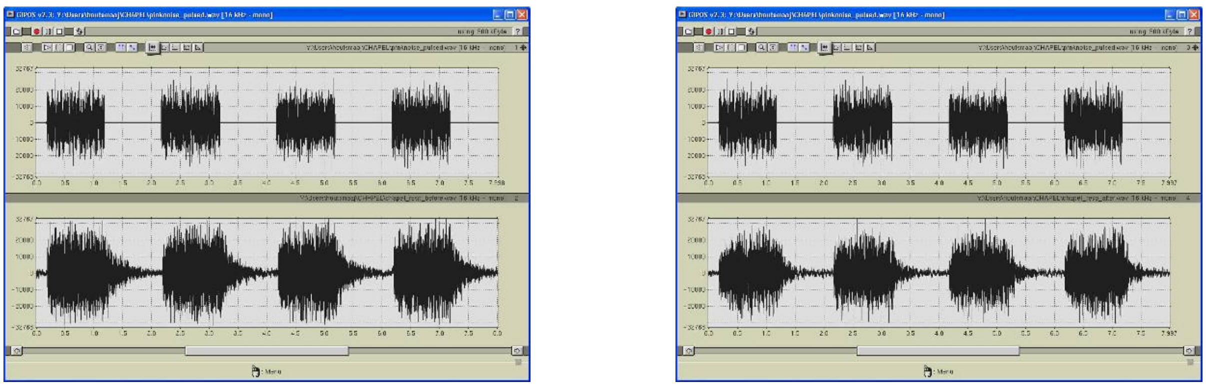


Figure 3. GIPOS display of sound stimulus and room responses before (left) and after (right) additional acoustic wall paneling was installed. Top traces are from the pink-noise stimuli, bottom traces are recorded room responses.

<u>Data analysis</u>

For broadband analysis and extraction of reverberation time, response records as shown in Figure 3 were sectioned in four, 1-s segments containing about 250 milliseconds (ms) of the "signal-on" and 750 ms of the "signal-off" condition. An example is shown in Figure 4 below.

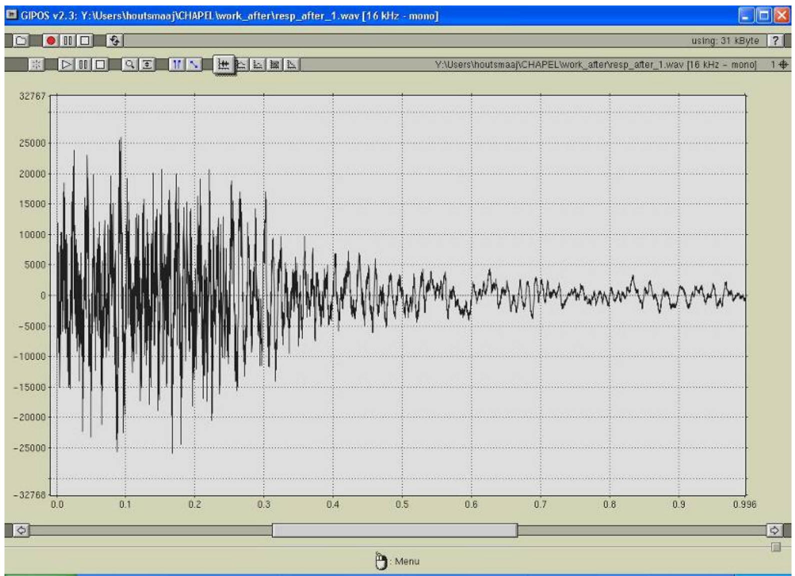
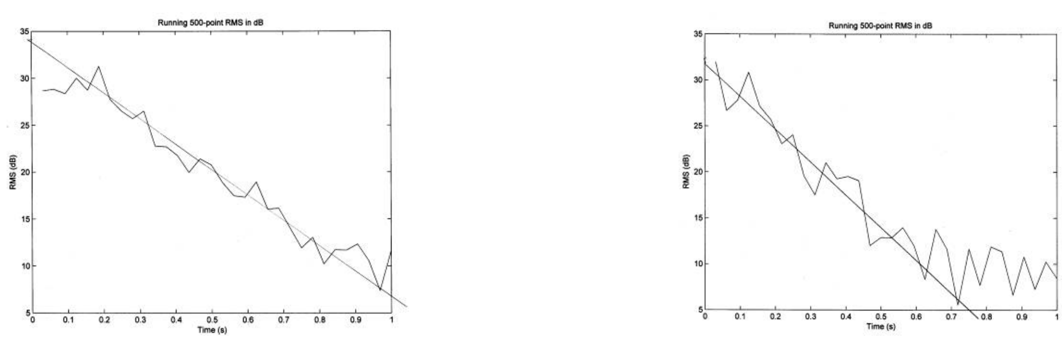


Figure 4. One-second sample of on-off process for broadband pink-noise room response.

The four, 1-s response data records collected for each of the two (before/after) conditions were then subjected to a root-mean-square (RMS) analysis over successive time frames of 31.25 ms. The RMS analysis was processed using the MATLAB script shown in Appendix D and yielded approximately 30 successive RMS values, one for each time frame. The logarithm of these values was plotted on an RMS (in dB) scale against linear time (in s), as shown in Figures 5a and 5b.



(a)   (b)

Figure 5. Examples of log RMS versus time plots for broadband responses before (a) and after (b) installation of additional sound-absorbing panels.

If sound decay is an exponential function of time, a logarithmic plot against linear time should yield a linear (straight-line) decay. All processed figures, like those in Figure 5, show such linear decay and can easily be fitted with a straight-line function. These reverberation time estimates are all shown in Appendix A. Notice that all results from the second ("after treatment") set of measurements, including Figure 5b, show a leveling-off effect near the end of the trace. The cause of this can easily be identified by listening to the recorded sounds, which indicate that during the second recording session a machine (e.g., vacuum cleaner) was running somewhere in the building. This background noise did not affect the measurement itself, but does restrict the sound decay range over which a linear decay slope can be estimated. Once a slope has been established, expressed in decibels per second (dB/s), the time span for which the sound would have decayed by 60 dB can easily be extrapolated. This is, per definition, the RT_{60} reverberation time.

For octave-band analysis, all 1-s broadband response samples were bandpass-filtered in octave bands centered at 125, 250, 500, 1000, 2000, and 4000 Hz. This was performed using the GIPOS digital filter function. The resulting sound functions, looking similar to the one shown in Figure 4 but sounding much more tonal, were subjected to the same log-RMS analysis and plotted against linear time. The resulting functions and their linear decay straight-line estimates are shown in Appendix B for measurements completed before, and in Appendix C for measurements completed after the installation of additional sound-absorbing material. From the straight-line fits, RT_{60} values were computed for every sample. Since for every conditions there were four independent samples, an average reverberation time was computed from the four samples taken for each condition.

Figure 6 illustrates the computed RT60 reverberation times for octave-band and broadband conditions both before and after the activity room's renovation with additional acoustic paneling. The results are further tabulated the Table below.

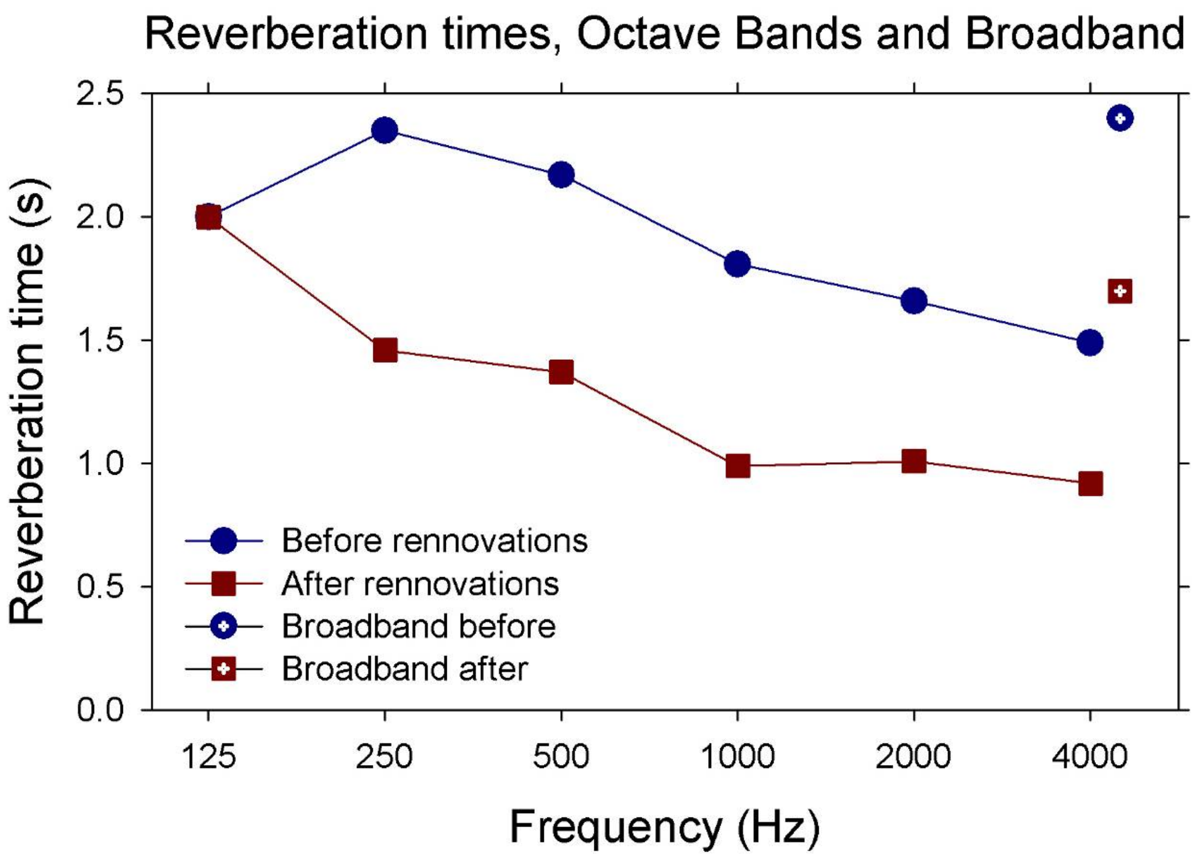


Figure 6. RT_{60} reverberation times as a function of octave-band center frequencies before (dark blue) and after (dark red) acoustical renovation. Broadband reverberation times are shown by the symbols on the right of the figure.

<u>Table.</u>
Averaged reverberation times before and after acoustic renovation.

Octave band center frequency (Hz)	RT_{60} (s) before renovation	RT_{60} (s) after renovation
125	2.00	2.00
250	2.35	1.46
500	2.17	1.37
1000	1.81	0.99
2000	1.66	1.01
4000	1.49	0.92
Broadband	2.40	1.70

Discussion

The quantitative effects of the acoustical renovation are consistent with observations expressed by activity room users, such that the acoustic environment of the activity room has noticeably improved. For frequencies in the speech band (300 to 3000 Hz), reverberation times were reduced by almost a factor two compared with previous values. A noticeable exception is the lowest measured frequency, 125 Hz, where the installation of wall-mounted sound-absorbing panel material had little or no effect. This was to be expected, since the type of absorbing paneling used is not designed for absorbing energy from waves that have an 8-ft wavelength. Consequently, if the space is used for amplified rock-type music, the acoustics of the space will tend to underscore and sustain the low-frequency drum beat.

If a new PA system is installed in the future, it is recommended that the system be tuned to a reduced sensitivity at selected low frequencies where the space will tend to set up standing-wave patterns. This will avoid unpleasant-sounding resonances and prevent possible system feedback.

<u>Appendix A.</u>
<u>Broadband reverberation time estimates.</u>

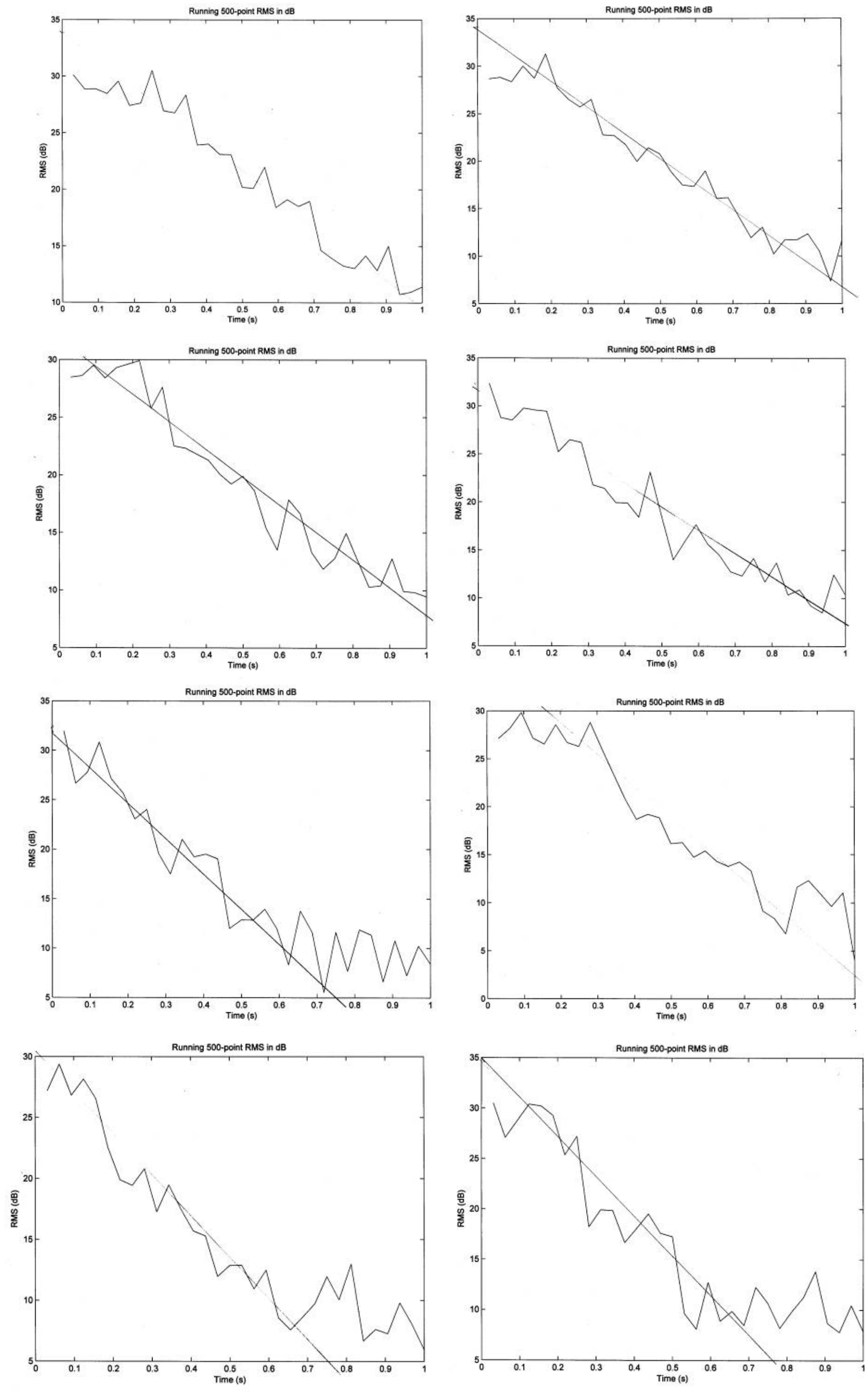


Figure A-1. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Four broadband samples before (top half) and after (bottom half) additional absorbing wall panels were installed.

Appendix B.
Sound decay estimates for octave bands before renovation.

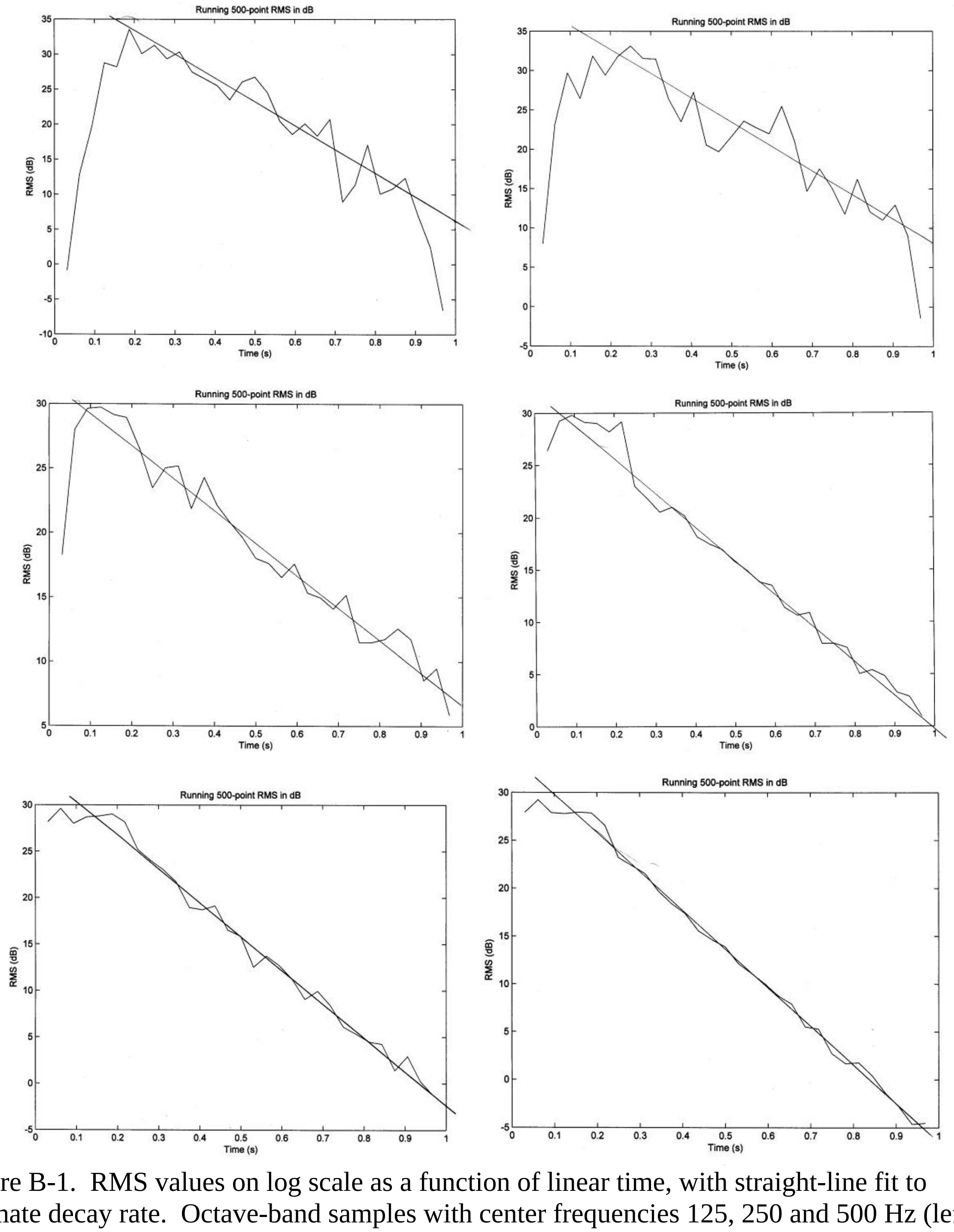


Figure B-1. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Octave-band samples with center frequencies 125, 250 and 500 Hz (left column) and 1000, 2000 and 4000 Hz (right column). Samples were measured before installation of additional acoustics panels. First sample set.

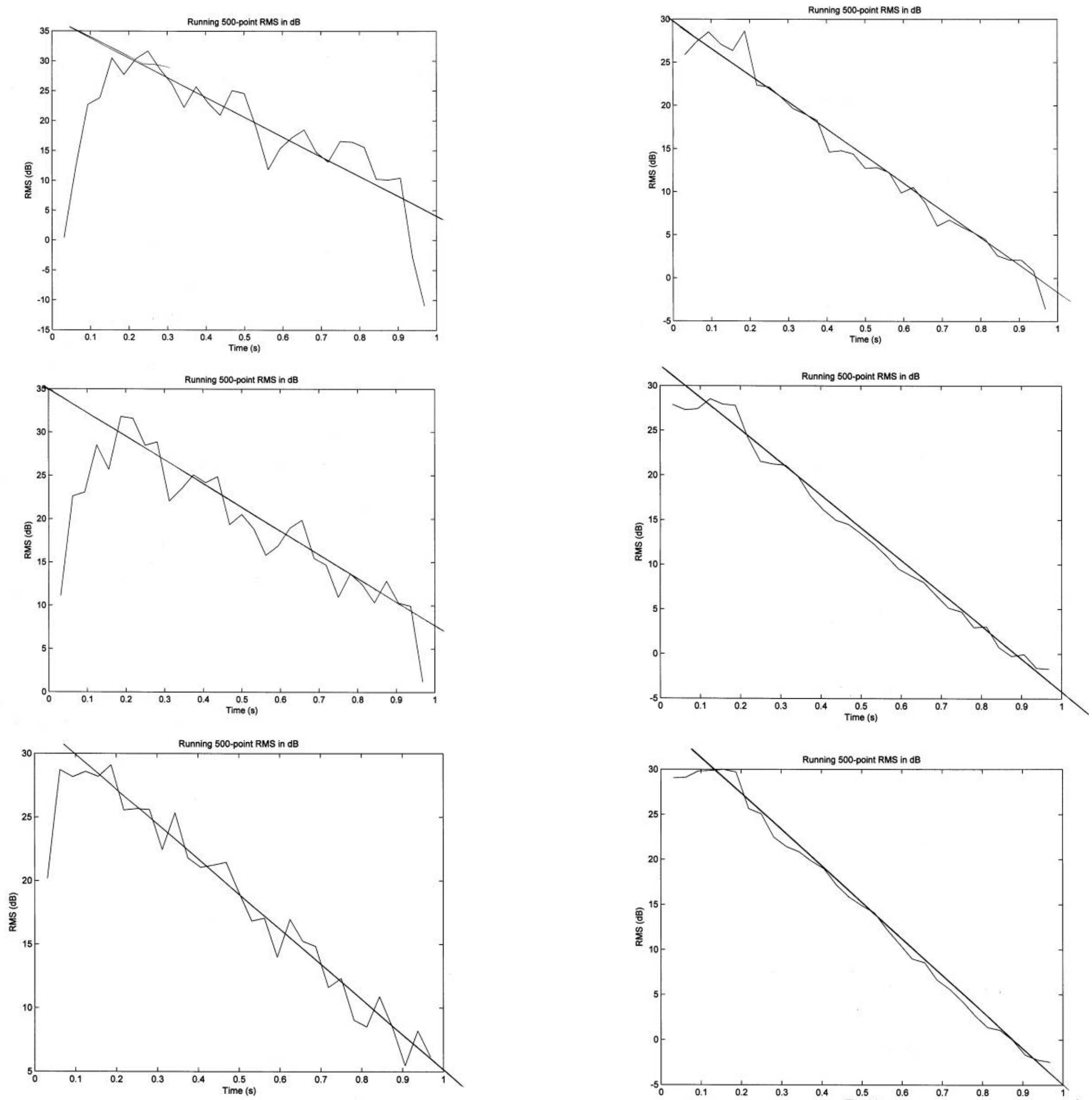


Figure B-2. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Octave-band samples with center frequencies 125, 250 and 500 Hz (left column) and 1000, 2000 and 4000 Hz (right column). Samples were measured before installation of additional acoustics panels. Second sample set.

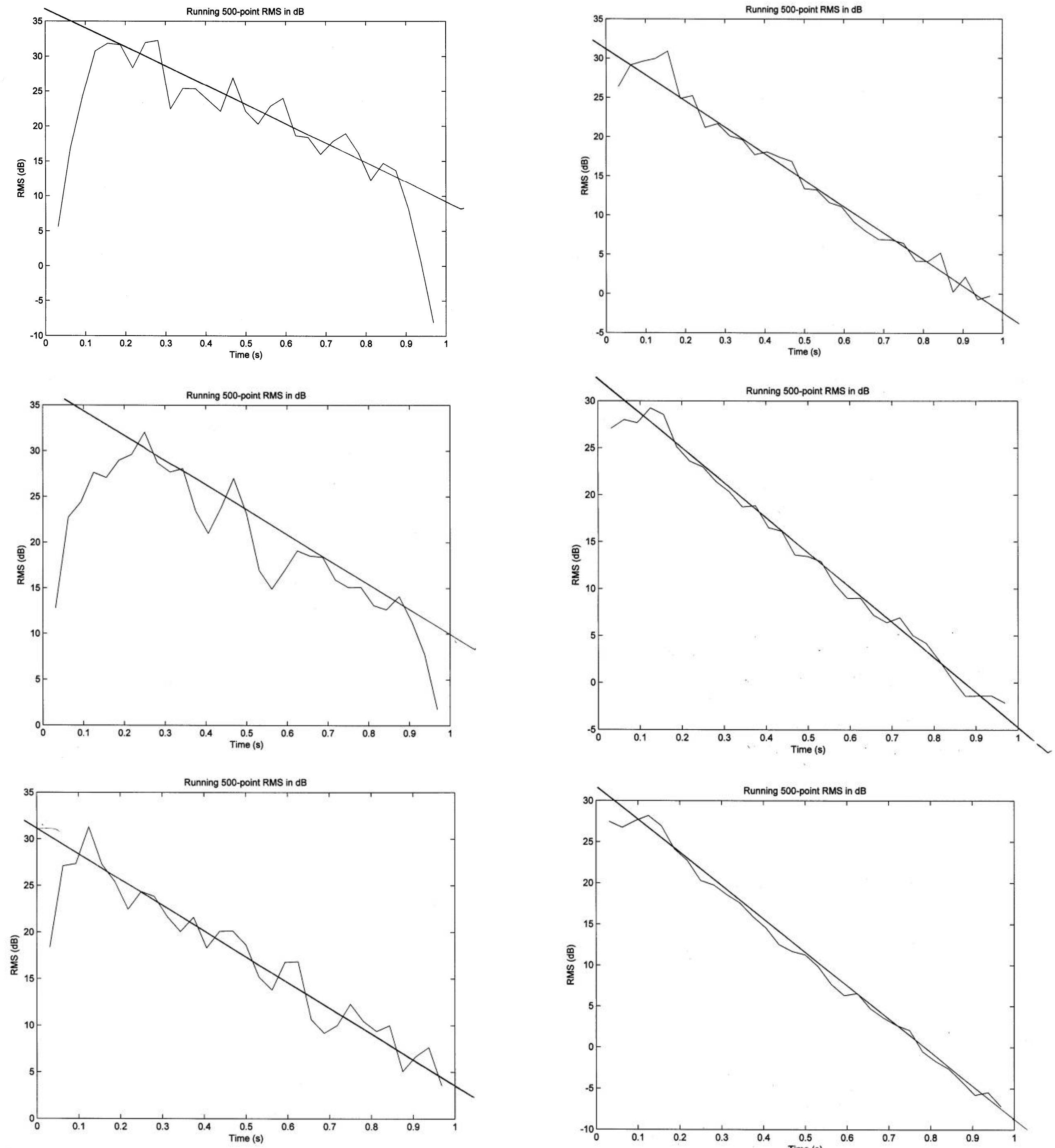


Figure B-3. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Octave-band samples with center frequencies 125, 250 and 500 Hz (left column) and 1000, 2000 and 4000 Hz (right column). Samples were measured before installation of additional acoustics panels. Third sample set.

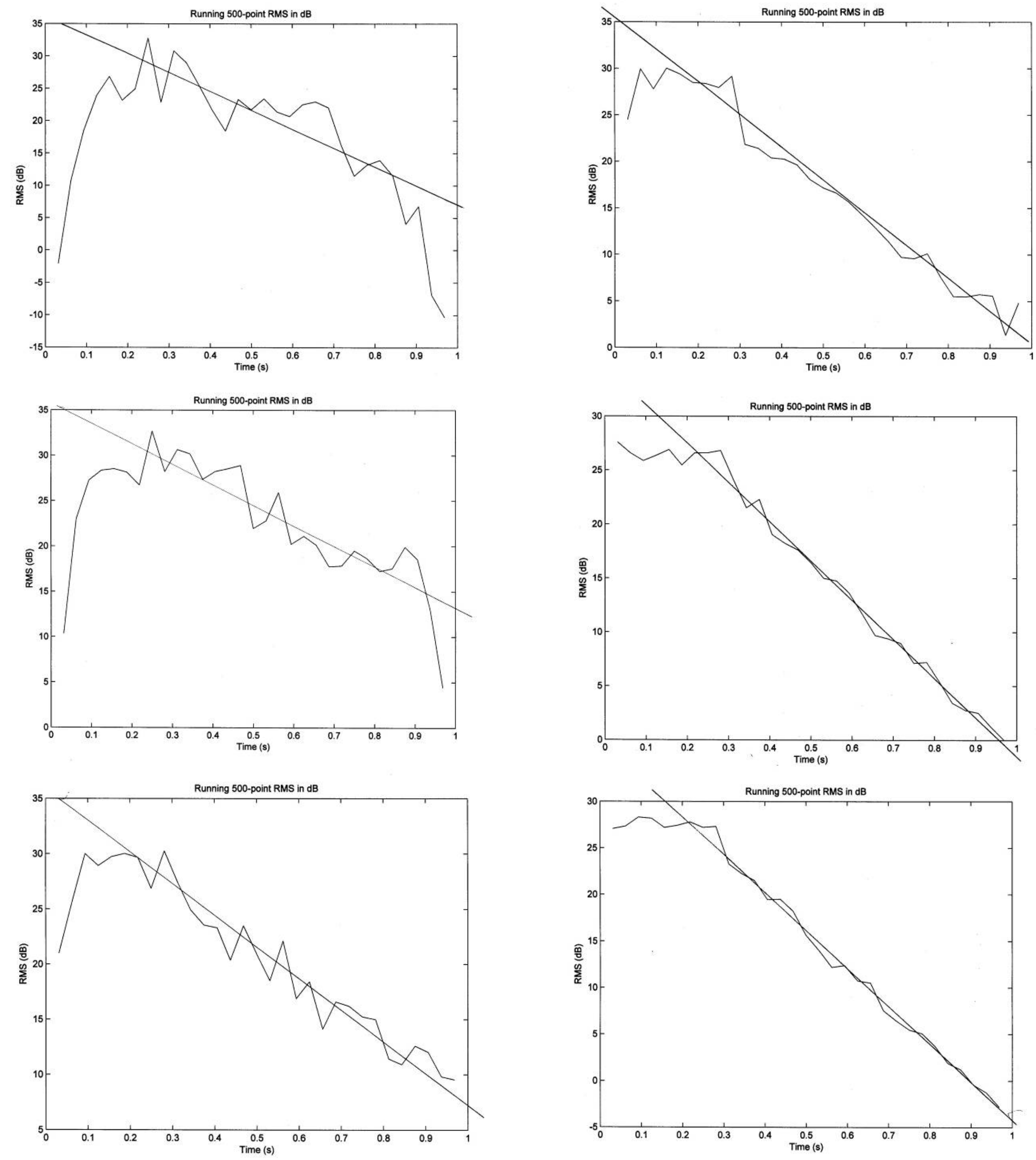


Figure B-4. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Octave-band samples with center frequencies 125, 250 and 500 Hz (left column) and 1000, 2000 and 4000 Hz (right column). Samples were measured before installation of additional acoustics panels. Fourth sample set.

Appendix C.
Sound decay estimates after renovation.

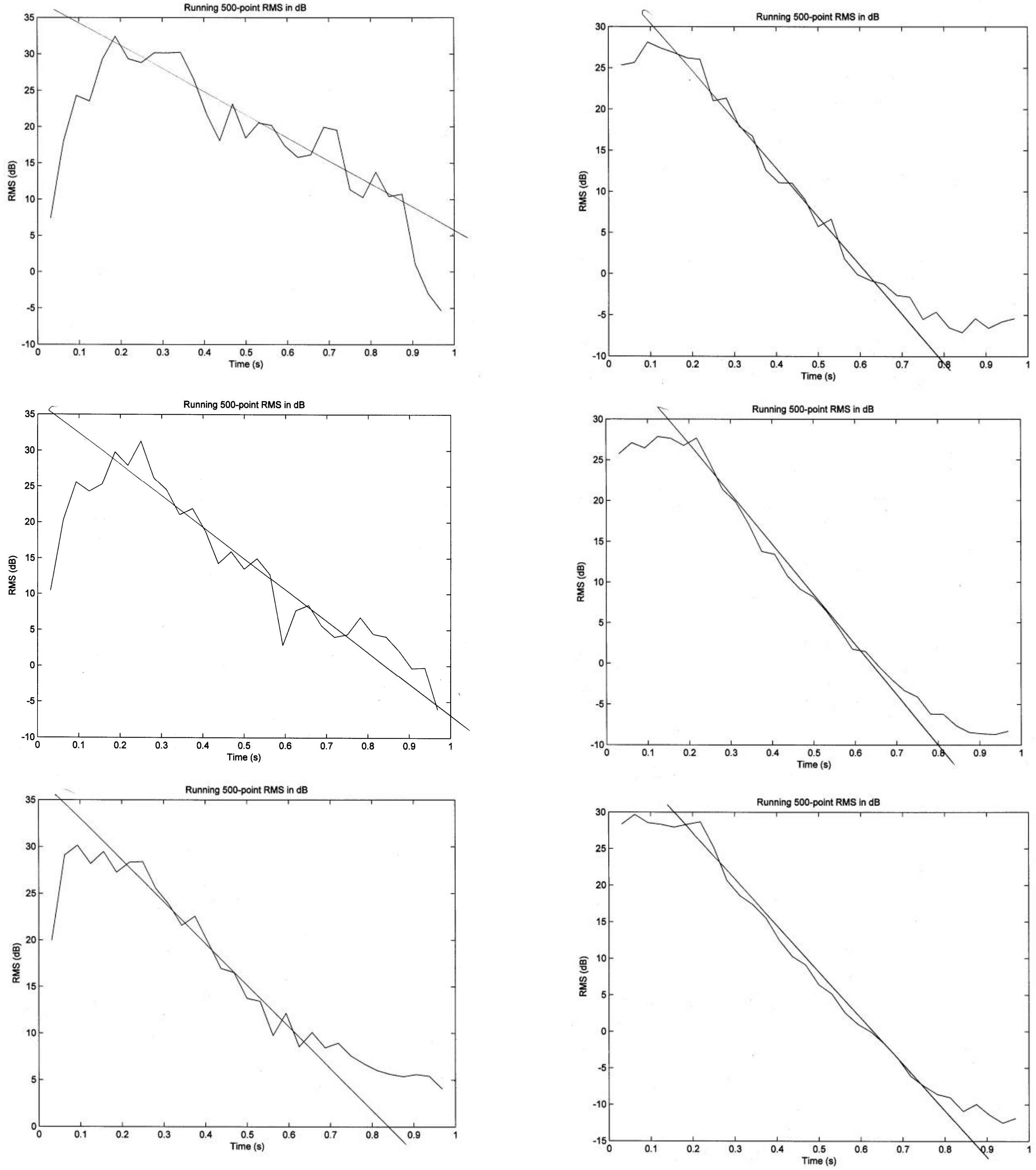


Figure C-1. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Octave-band samples with center frequencies 125, 250 and 500 Hz (left column) and 1000, 2000 and 4000 Hz (right column). Samples were measured after installation of additional acoustics panels. First sample set.

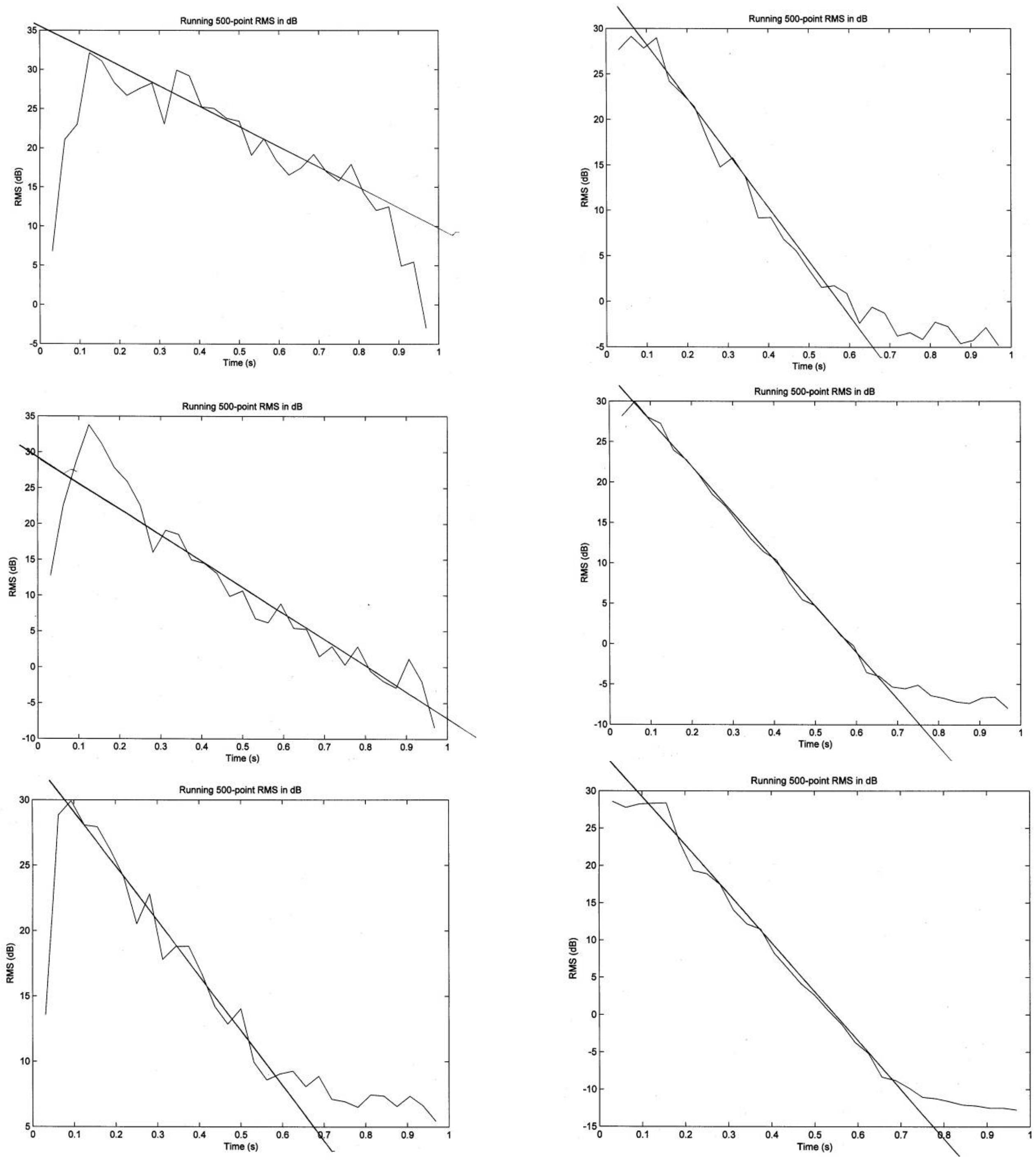


Figure C-2. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Octave-band samples with center frequencies 125, 250 and 500 Hz (left column) and 1000, 2000 and 4000 Hz (right column). Samples were measured after installation of additional acoustics panels. Second sample set.

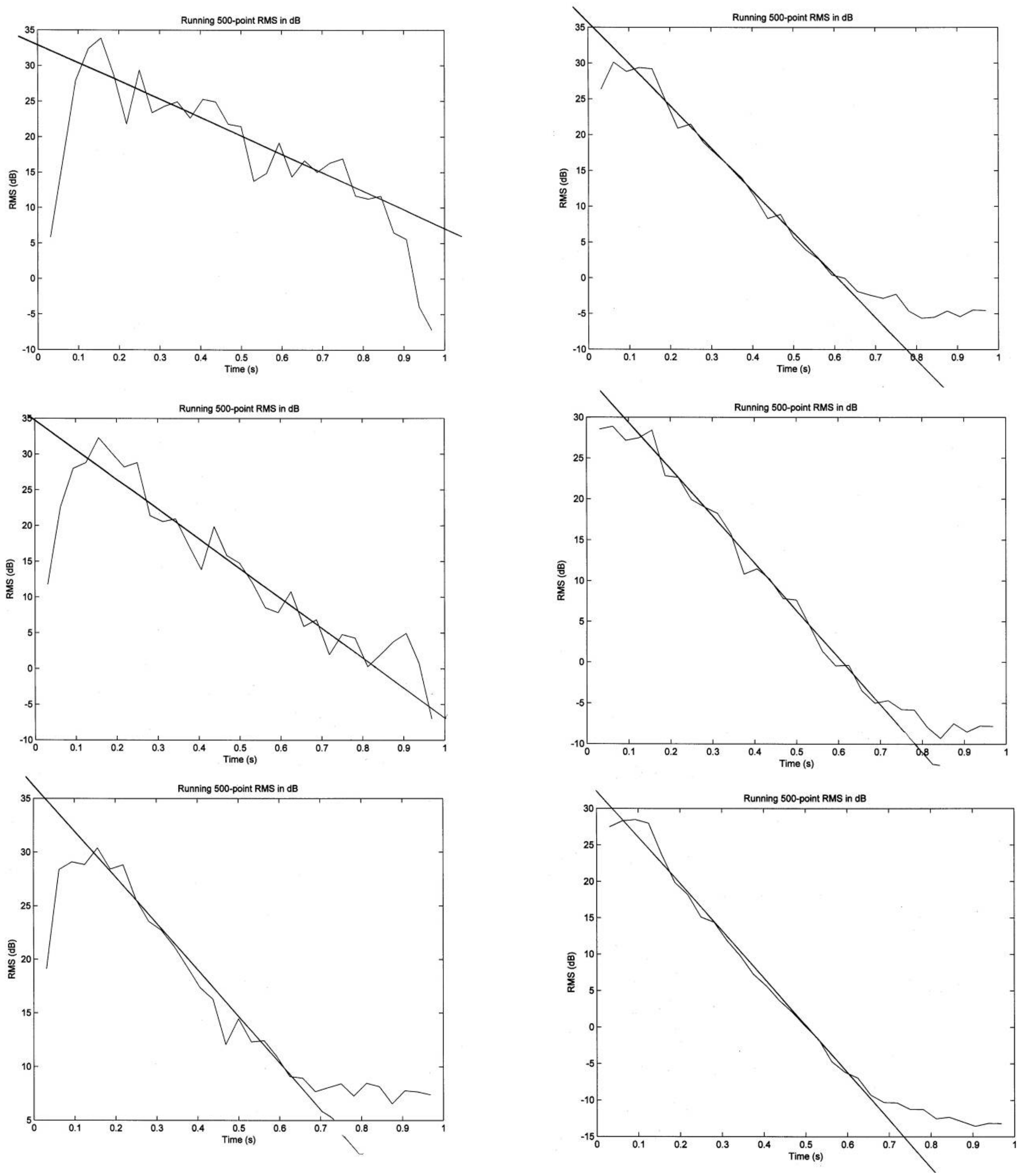


Figure C-3. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Octave-band samples with center frequencies 125, 250 and 500 Hz (left column) and 1000, 2000 and 4000 Hz (right column). Samples were measured after installation of additional acoustics panels. Third sample set.

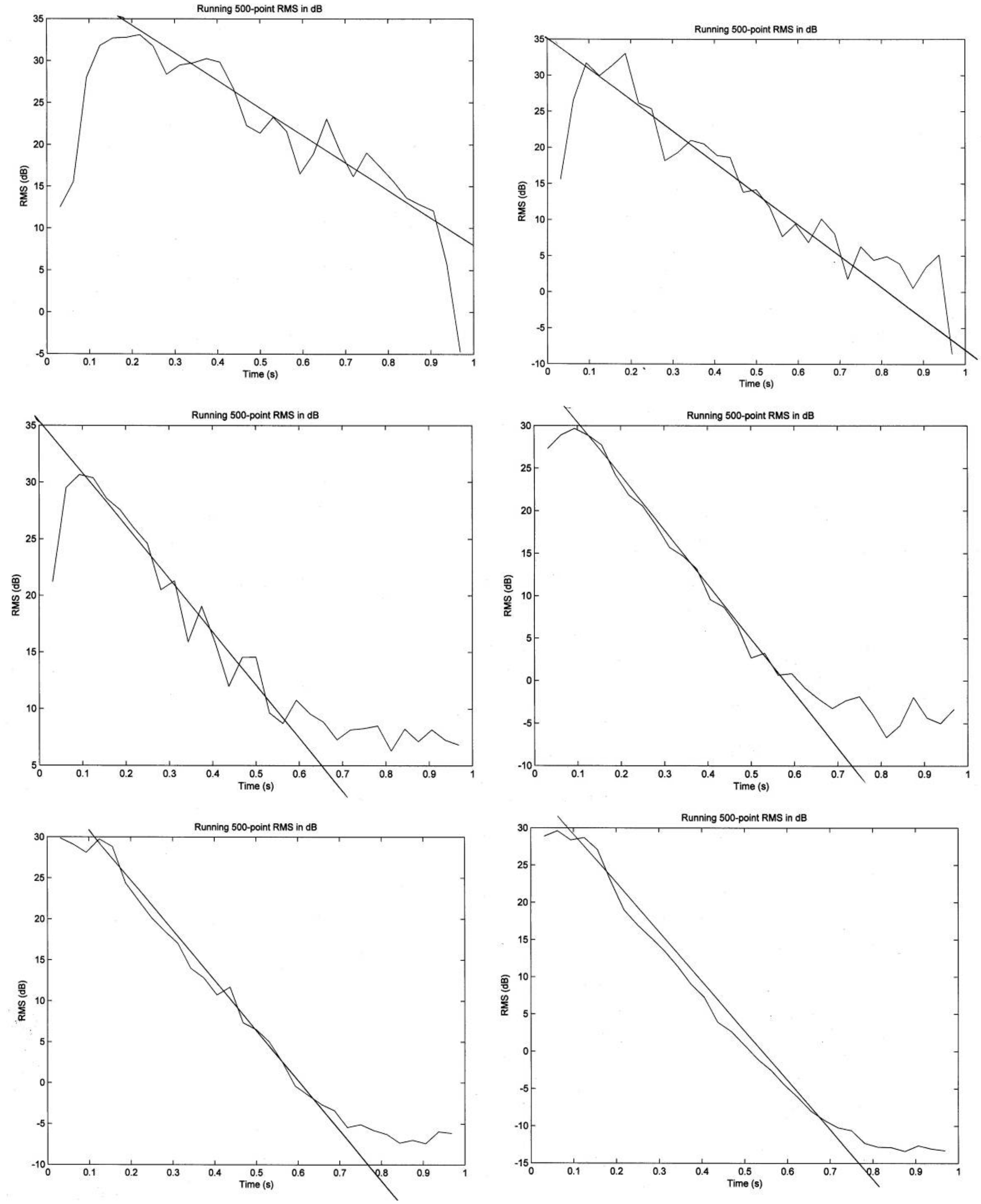


Figure C-4. RMS values on log scale as a function of linear time, with straight-line fit to estimate decay rate. Octave-band samples with center frequencies 125, 250 and 500 Hz (left column) and 1000, 2000 and 4000 Hz (right column). Samples were measured after installation of additional acoustics panels. Fourth sample set.

Appendix D.

MATLAB script to compute and plot 31.25-ms-window RMS values.

```
%Program to read 'wav' files and compute & plot running RMS values
%over sequential blocks of 500 points in logarithmic (dB) units.

file=input('filename?  ','s');
[wav,sf,bits]=wavread(file);
l=size(wav);
l=l(1);
for i=1:500:l-500
    sumsq=0;
    for j=i:i+499
        sumsq=sumsq+wav(j,1)^2;
    end
    m=(i-1)/500+1;
    rms(m,1)=100*sqrt(sumsq/500.0);
    l_rms(m,1)=20*log10(rms(m,1));
end
kend=size(l_rms);
kend=kend(1);
k=1:kend;
t=500*k'/sf;
plot(t,l_rms)
title('Running 500-point RMS in dB');
xlabel('Time (s)');
ylabel('RMS (dB)');
```

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